Appendix F

AIR QUALITY MONITORING CONSIDERATIONS FOR THE EASTERN RIVERS AND MOUNTAINS NETWORK

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Introduction

As part of the National Park Service (NPS) Inventory and Monitoring (I&M) Program's Vital Signs scoping process, the Eastern Rivers and Mountains Network (ERMN) will evaluate the need for ambient air quality and air pollution effects monitoring in Network parks. This report contains background and summary air quality information to assist Network staff in that effort. On-site and nearby off-site ambient air quality data were used in conjunction with park-specific resource information to evaluate the following relative to the ERMN: 1) the need for additional ambient air quality monitoring at any Network park, i.e., wet deposition, dry deposition, visibility, and/or ozone monitoring, and 2) the need for air quality effects-related monitoring at any Network park. The results of this evaluation are discussed below.

The evaluation for ERMN parks relied on data collected through a number of Federal- and state-sponsored ambient air quality monitoring programs. Monitor locations, site numbers, and distances from ERMN parks are provided in Tables 1 and 2. Maps displaying monitor locations and graphics summarizing monitoring data are provided in a separate PowerPoint file as an addendum to this report.

The evaluation used products developed by the NPS Air Resources Division (ARD) specifically for the I&M Program. In 2004, the ARD finalized an Air Quality Inventory for I&M parks. The Air Quality Inventory consists of GIS-based maps and associated look-up tables that provide baseline values for a set of air quality parameters for all I&M parks. The values are based on averaged 1995 to 1999 data. Because ozone is a regional pollutant, in most cases the look-up table values are likely representative of ozone concentrations in a park. Greater variability, and uncertainty, may exist for deposition and visibility values, since those pollutants are more likely to be influenced by meteorological differences. Air Quality Inventory products are contained in the NPS Air Atlas (http://www2.nature.nps.gov/air/maps/airatlas/). NPS Air Atlas estimates for select air quality parameters for ERMN parks are provided in Appendix 1 of this report, and a description of those parameters is provided in Appendix 2.

In an ongoing project, ARD contracted with an ozone effects expert to assess the risk of ozone-induced foliar injury on sensitive vegetation in I&M parks. The risk assessments are based on NPS Air Atlas ozone values, the Palmer Z Drought Index and park vascular plant lists. The risk assessments will be finalized, distributed, and posted on the ARD website in summer 2004. In the meantime, draft risk assessments for the ERMN are attached as Appendix 3.

Wet Deposition

The National Atmospheric Deposition Program/National Trends Network (NADP/NTN) is a nationwide network of precipitation monitoring sites. The network is a cooperative effort between many different groups, including the U.S. Environmental Protection Agency (EPA), U.S. Geological Survey, U.S. Department of Agriculture, and private entities. The NPS is a major participant in NADP/NTN, and the ARD recommends that any new wet deposition site installed in a park meet NADP/NTN siting criteria and follow NADP/NTN monitoring protocols. There are currently more than 200 NADP/NTN sites spanning the continental U.S., Alaska, Puerto Rico, and the Virgin Islands (http://nadp.sws.uiuc.edu/).

The purpose of the NADP/NTN network is to collect data on the chemistry of precipitation in order to monitor geographical and temporal long-term trends. The precipitation at each station is collected weekly according to strict clean-handling procedures. It is then sent to the Central Analytical Laboratory in Illinois where it is analyzed for hydrogen (acidity as pH), sulfate (SO_4), nitrate (NO_3), ammonium (NH_4), chloride, and base cations (such as calcium, magnesium, potassium and sodium). NADP/NTN's excellent quality assurance programs ensure that the data remain accurate and precise.

The NADP/NTN has also expanded its sampling to include the Mercury Deposition Network (MDN), which currently has over 35 sites. The MDN was formed in 1995 to collect weekly samples of precipitation, which are analyzed for total mercury. The objective of the MDN is to monitor the amount of mercury in precipitation on a regional basis (http://nadp.sws.uiuc.edu/mdn/).

The Pennsylvania Department of Environmental Protection (DEP), under a cooperative agreement with Pennsylvania State University, has maintained the Pennsylvania Atmospheric Deposition Monitoring Network since 1981. The purpose of the DEP program is to determine how much atmospheric deposition is falling in precipitation in the state (http://www.dep.state.pa.us/dep/deputate/airwaste/aq/acidrain/acidrain.htm). The DEP supports nine wet atmospheric deposition and six wet mercury deposition monitoring sites. The Pennsylvania Atmospheric Deposition Monitoring Network monitors the same parameters, follows the same protocols and uses the same quality assurance programs as NADP/NTN and MDN. More than half of the Pennsylvania Atmospheric Deposition Monitoring Network sites are in the NADP/NTN, and all the Pennsylvania DEP mercury monitoring sites are in the MDN.

Deposition varies with the amount of annual on-site precipitation, and is useful because it gives an indication of the total annual pollutant loading at the site. Concentration is independent of precipitation amount, therefore, it provides a better indication of whether ambient pollutant levels are increasing or decreasing over the years. In general, annual average wet deposition and concentration of SO_4, NO_3, and NH_4 are higher in the eastern than in the western U.S. At many NADP/NTN sites across the U.S., concentration and deposition of SO_4 have declined in recent years as sulfur dioxide emissions have decreased. Trends have been variable for NO_3 and NH_4, with concentration and deposition at various sites increasing, decreasing, or showing no overall change.

Trend analyses have not yet been performed for MDN sites due to the relatively short time that sites have been in operation. MDN site PA13 (Allegheny Portage Railroad National Historic Site

(NHS)) has been operating since 1997, site PA37 (Holbrook) has been operating since 1999, and site PA72 (Milford) was installed in 2000. MDN deposition maps show that, similar to SO_4 and NO_3, wet mercury deposition is higher in the eastern U.S. than in the western U.S. Highest wet mercury deposition values are consistently monitored at sites in Florida and along the Gulf of Mexico.

Allegheny Portage Railroad NHS has Pennsylvania Atmospheric Deposition Monitoring Network atmospheric deposition and mercury deposition monitors on-site; the rest of the parks in the ERMN have either a Pennsylvania Atmospheric Deposition Monitoring Network or a NADP/NTN monitor within 60 km. The 2002 NADP/NTN and Pennsylvania Atmospheric Deposition Monitoring Network wet deposition values for the ERMN were similar, and were consistent with the 1995 through 1999 Network averages contained in the NPS Air Atlas. Sulfate, NO_3 and NH_4 wet deposition ranged from about 16 to 25 kilograms per hectare per year (kg/ha/yr), 14 to 19 kg/ha/yr, and 2.3 to 3.7 kg/ha/yr, respectively. Converted to sulfur (S) and nitrogen (N), the ranges for the NADP/NTN and Pennsylvania Atmospheric Deposition Monitoring Network values were 5.3 to 8.3 kg/ha/yr for wet S deposition, and 4.9 to 7.1 kg/ha/yr for wet N deposition. The Air Atlas wet deposition values for ERMN parks were 4.4 to 6.6 kg/ha/yr for S and 3.5 to 6.8 kg/ha/yr for N. The NADP/NTN and Pennsylvania Atmospheric Deposition Monitoring Network wet concentration values for SO_4, NO_3 and NH_4 ranged from about 1.4 to 2.2 milligrams per liter (mg/l), 1.1 to 1.6 mg/l, and 0.2 to 0.34 mg/l, respectively.

With the exception of Bluestone National Scenic River (NSR), Gauley River National Recreation Area (NRA) and New River Gorge National River (NR), the remaining ERMN parks have a MDN monitor within 60 km. 2002 Mercury wet deposition values ranged from 9.1 to 9.4 micrograms per square meter, while mercury wet concentration values ranged from 7.7 to 9.0 nanograms per liter.

Trend results for NADP/NTN and Pennsylvania Atmospheric Deposition Monitoring Network sites in and near ERMN parks are summarized below.

Allegheny Portage Railroad NHS

Allegheny Portage Railroad NHS has been a Pennsylvania Atmospheric Deposition Monitoring Network site (PA13) since 1997. Data showed an increase in wet SO_4, NO_3 and NH_4 concentration, but no apparent trend in wet SO_4, NO_3 or NH_4 deposition.

State College

An NADP/NTN site (PA15 (Penn State)) has been operating at State College since 1983. Data showed a decrease in wet concentration and deposition of SO_4 and NO_3, but no apparent trend in NH_4 concentration and deposition.

Holbrook

The Holbrook Pennsylvania Atmospheric Deposition Monitoring Network site (PA37) has been operating since 1999. Trend data are not yet available for the site.

Pine Grove Mills

The Pine Grove Mills, Pennsylvania, NADP/NTN site (PA42 (Leading Ridge)) has been operating since 1979. Data showed a decrease in wet SO_4 concentration and deposition, but no apparent trend in concentration and deposition of NO_3 or NH_4.

Milford

Milford, Pennsylvania has had a NADP/NTN site (PA72) since 1983. Data showed a decrease in wet SO_4 and NO_3 deposition and concentration, but no apparent trend in wet NH_4 concentration and deposition.

Eggleston

The NADP/NTN site has been operating in Eggleston, Virginia (VA13 (Horton Station)) since 1978. Trend data are only available since 1987. Data showed a decrease in wet SO_4 concentration and deposition, but no apparent trend in concentration and deposition of NO_3 or NH_4.

Babcock State Park

Babcock State Park, West Virginia, has had a NADP/NTN site ((WV04) since 1983. Data showed a decrease in wet SO_4 concentration and deposition, but no apparent trend in concentration and deposition of NO_3 or NH_4.

Cedar Creek State Park

There has been a NADP/NTN site at Cedar Creek State Park, West Virginia (WV05), since 1999. Trend data are not yet available for the site.

Dry Deposition

The Clean Air Status and Trends Network (CASTNet) is the nation's primary source for atmospheric data to estimate dry acidic deposition. Established in 1987, CASTNet now comprises over 70 monitoring stations across the U.S. The majority of the monitoring stations are operated by EPA; however, approximately 20 stations are operated by the NPS in cooperation with EPA (http://www.epa.gov/castnet/). Each CASTNet dry deposition station measures: weekly average atmospheric concentrations of SO_4, NO_3, NH_4, sulfur dioxide, and nitric acid; hourly concentrations of ambient ozone; and meteorological conditions required for calculating dry deposition rates. Dry deposition rates are calculated using atmospheric pollutant concentrations, meteorological data, and information on land use, vegetation, and surface conditions. CASTNet complements the database compiled by NADP/NTN; therefore, CASTNet sites are located at or near NADP/NTN sites. Dry deposition monitoring is more difficult, and more expensive, than wet deposition monitoring; consequently, there are fewer CASTNet than NADP/NTN sites nationwide. Due to the small number of CASTNet sites, it is not possible to develop dry deposition isopleth maps such as those produced by NADP/NTN. Because CASTNet uses different monitoring and reporting techniques than NADP/NTN, the dry deposition amounts are reported as S and N, rather than SO_4, NO_3 and NH_4. In addition, because CASTNet calculates dry deposition based on estimated deposition velocities, there is greater uncertainty in the reported values.

None of the ERMN parks have a CASTNet monitor on-site, but all parks have a monitor within 80 km. Data summaries and trend analyses for CASTNet sites near ERMN parks are provided below.

All trend analyses cover the timeframe of 1989 through 2001, except for the Claryville site, which began in 1994.

Washington Crossing

The Washington Crossing, New Jersey, CASTNet site (WSP144) data showed decreasing trends in both dry S deposition and dry N deposition. Total S deposition at Washington Crossing was composed of 47 percent dry deposition and 53 percent wet deposition, while total N deposition was 35 percent dry and 65 percent wet.

Claryville

Data from the Claryville, New York, CASTNet site (CAT175) showed no apparent trend in dry S deposition, but a decreasing trend in dry N deposition. Total S deposition at Claryville was composed of 37 percent dry deposition and 73 percent wet deposition, while total N deposition was 33 percent dry and 67 percent wet.

State College

The State College, Pennsylvania, CASTNet site (PSU106 (Pennsylvania State University)) data showed a decreasing trend in dry S deposition, but no apparent trend in dry N deposition. Total S deposition at State College was composed of 51 percent dry deposition and 49 percent wet deposition, while total N deposition was 31 percent dry and 69 percent wet.

Laurel Hill State Park

Laurel Hill State Park, Pennsylvania, CASTNet site (LRL117) data showed a decreasing trend in dry S deposition, but no apparent trend in dry N deposition. Total S deposition at the site was composed of 46 percent dry deposition and 54 percent wet deposition, while total N deposition was 24 percent dry and 76 percent wet.

Eggleston

Data from the Eggleston, Virginia, CASTNet site (VPI120 (Horton Station)) showed a decreasing trend in dry S deposition, but no apparent trend in dry N deposition. Total S deposition at the site was composed of 48 percent dry deposition and 52 percent wet deposition, while total N deposition was 48 percent dry and 52 percent wet.

Cedar Creek State Park

The Cedar Creek State Park, West Virginia, CASTNet site (CDR119) data indicated a decreasing trend in dry S deposition, but no apparent trend in dry N deposition. Total S deposition at Cedar Creek State Park was composed of 25 percent dry deposition and 75 percent wet deposition, while total N deposition was 20 percent dry and 80 percent wet.

Surface Water and Fish Tissue Chemistry

It is generally accepted that surface waters with a pH below 6.0 and an acid neutralizing capacity (ANC) below 100 microequivalents per liter (μeq/l) are sensitive to acidification from atmospheric deposition. The ERMN is in a part of the country that has been heavily impacted by past and current mining activities, and water quality data from many of the Network parks typify surface waters affected by acid mine drainage. In such areas, impacts from atmospheric deposition would likely be inconsequential compared to those from mining.

For this evaluation, the NPS Water Resources Division's (WRD) *Baseline Water Quality Data Inventory and Analysis* reports were reviewed for all of the ERMN parks. In addition, state agency and the NPS Research Permit and Reporting System websites were reviewed for reports of any additional, relevant surface water chemistry data. The websites were also reviewed for information pertaining to any chemical analyses conducted on aquatic biota collected in park lakes, rivers, and streams. The results of the review are summarized below.

<u>Allegheny Portage Railroad NHS and Johnstown Flood National Memorial (NMem)</u>

A review of the 1999 *Baseline Water Quality Data Inventory and Analysis* report for Allegheny Portage Railroad NHS and Johnstown Flood NMem indicated surface waters in the area have been affected by mining and oil and gas development. Some water quality samples collected at acid mine discharge points in the parks had pH values less than 4.0 and ANC values of 0 μeq/l. Samples collected at Blair Gap Run, Marshy Tributary, and South Fork Little Conemaugh River had average pH values of about 6.5. Some of the samples had ANC values below 100 μeq/l; however, it was not clear if those water bodies were affected by acid mine drainage. Pennsylvania has a general, statewide fish consumption advisory to limit ingestion of contaminants from untested fish. In addition, more stringent advisories are in effect for a number of lakes and rivers in the Ohio and Susquehanna River Basins. These advisories are primarily for mercury, but in some locations, polychlorinated biphenyls (PCBs) or chlordane are also of concern (http://sites.state.pa.us/PA_Exec/Fish_Boat/fishpub/summary/sumconsumption.pdf).

<u>Bluestone National Scenic River (NSR)</u>

The 1995 *Baseline Water Quality Data Inventory and Analysis* report for Bluestone NSR indicated area surface waters have been affected by residential development, farming and coal mining. Water quality samples were collected in the park on Bluestone River, Little Bluestone River and Mountain Creek from 1960 to 1995. The samples had an average pH of about 7.5 and average ANC values well above 100 μeq/l. Surface waters in Bluestone NSR do not seem to be sensitive to acidification from atmospheric deposition. It does not appear that West Virginia has issued a fish consumption advisory for Bluestone NSR (http://www.wv.gov/Offsite.aspx?u=http://www.dep.state.wv.us/).

<u>Delaware Water Gap National Recreation Area (NRA) and Upper Delaware Scenic and Recreational River (S&RR)</u>

The 1995 *Baseline Water Quality Data Inventory and Analysis* report for Delaware Water Gap NRA and Upper Delaware S&RR indicated the area has relatively good water quality. Water samples were collected from the Delaware River, as well as from a number of creeks and brooks in the area. All in-park pH values averaged 6.5 to 7.5. Relatively few ANC values were included in the WRD report and most of those data were collected prior to 1975. Some of the reported ANC values were below 100 μeq/l, but given the chemical techniques available at the time, the data may not be accurate. Extensive water quality sampling continues in both parks under the auspices of the New Jersey and Pennsylvania Departments of Environmental Protection, the U.S. Geological Survey and the Delaware River Basin Commission. Data collected at Long Pine Pond, in Delaware Water Gap NRA, indicates the pond may be acidic, with reported pH values of 5.5 and ANC values of zero. It is not clear if this pond is affected by acid mine drainage or some other point source of pollution. Fish, freshwater eels and invertebrates have also been collected in the Delaware River for chemical analyses. Based on samples collected in the mid-1990s, the Delaware River Basin has fish consumption advisories for mercury and PCBs.

Fort Necessity National Battlefield (NB)

A review of the 1997 *Baseline Water Quality Data Inventory and Analysis* report for Fort Necessity NB indicated sufficient data do not exist to determine the sensitivity of park surface waters to acidification. The only reported data were collected from one spring in the park in 1977. That sample had a pH of 6.0 and an ANC value of 400 μeq/l. Fish consumption advisories are in effect for many lakes and streams in the Ohio River Basin for mercury, PCBs and/or chlordane.

Friendship Hill National Historic Site (NHS)

The 1998 *Baseline Water Quality Data Inventory and Analysis* report for Friendship Hill NHS indicated surface waters in the area are affected by oil and gas development and mining. Previous in-park sampling focused on an area of active mine drainage into Ice Pond Run. It doesn't appear synoptic surface water chemistry sampling has been conducted in the park. Therefore, it is not possible to determine the sensitivity of surface waters in the park to acidification from atmospheric deposition. Fish consumption advisories are in effect for many lakes and streams in the Ohio River Basin for mercury, PCBs and/or chlordane. There is an advisory for the Monongahela River in Point Marion for PCBs and chlordane.

Gauley River National Recreation Area (NRA)

A review of the 1995 *Baseline Water Quality Data Inventory and Analysis* report for Gauley River NRA showed the area has been impacted by development and mining. Limited, but recent, in-park data exist for Gauley River, Meadow River and Peters Creek. The data indicate Peters Creek and Meadow Creek are well-buffered. Water samples from Gauley River had pH values of 6.7 to 6.8 and average ANC values of about 70 μeq/l. Typically, one would expect much higher ANC values in water samples with pH values above 6.0. The reason for the discrepancy in these values is unknown. It does not appear that West Virginia has issued a fish consumption advisory for the Gauley River.

New River Gorge National River (NR)

The 1995 *Baseline Water Quality Data Inventory and Analysis* report for New River Gorge NR indicated surface waters in the area have been affected by mining. The report showed that while the New River and most creeks in the park are well-buffered, Mill Creek and Dowdy Creek had pH values of 7.0 but ANC values below 100 μeq/l. The reason for the discrepancy between pH and ANC values is unknown. It does not appear that West Virginia has issued a fish consumption advisory for New River Gorge NR.

Particulate Matter

Small or "fine" particles in the air, typically those less than 2.5 microns in diameter, $PM_{2.5}$, are a leading cause of human respiratory illness. Particles are present everywhere, but high concentrations and/or specific types have been found to present a serious danger to human health. Fine particles in the air are also the main contributor to human-caused visibility impairment. The particles not only decrease the distance one can see; they also reduce the colors and clarity of scenic vistas.

The current human-health based National Ambient Air Quality Standards (NAAQS) for particulate matter (set by the EPA) are for particles 10 microns or less in diameter (PM_{10}). Areas where air quality exceeds the NAAQS for PM_{10} are designated "nonattainment" for that pollutant. There are PM_{10} monitors within 35 km of Allegheny Portage Railroad NHS, Delaware Water Gap NRA, Fort Necessity NB, Friendship Hill NHS and Johnstown Flood NMem. No designated PM_{10} nonattainment areas are located near ERMN parks (http://www.epa.gov/air/data/index.html).

In 1997, EPA finalized new stricter NAAQS for particulate matter based on $PM_{2.5}$. Nationwide $PM_{2.5}$ monitoring was initiated in 1999; nonattainment areas will not be designated until December 2004. There are $PM_{2.5}$ monitors within 35 km of Bluestone NSR, Delaware Water Gap NRA, Fort Necessity NB, Friendship Hill NHS, Gauley River NRA, and New River Gorge NR. Preliminary monitoring data for 2000 through 2002 indicate there will be no designated $PM_{2.5}$ nonattainment areas near parks of the ERMN (http://www.epa.gov/ttn/naaqs/pm/pm25_tech_info.html).

Visibility

In 1985, in response to the mandates of the Clean Air Act, Federal and regional/state organizations established the Interagency Monitoring of Protected Visual Environments (IMPROVE) program to protect visibility in Class I air quality areas. Class I areas are national parks greater than 5,000 acres and wilderness areas greater than 6,000 acres, that were established prior to August 7, 1977. All other NPS areas are designated Class II. The objectives of the IMPROVE program are to: establish current visibility conditions in all Class I areas; identify pollutants (particles and gases) and emission sources responsible for existing man-made visibility impairment; and document long-term trends in visibility. The IMPROVE network is designed to assess regional visibility; standard operation does not identify individual sources that impair visibility at a monitoring site (http://vista.cira.colostate.edu/improve/).

In 1999, there were 30 official IMPROVE sites and 40 protocol sites. Because of recently enacted Regional Haze regulations that require improving visibility in Class I areas, the number of visibility monitors has increased. Protocol sites were upgraded to full IMPROVE sites and 80 new sites were added to the IMPROVE network. While the IMPROVE program has focused on Class I air quality areas, a great deal of visibility monitoring has been conducted in Class II areas. Installation and annual operating costs for a full IMPROVE site are expensive. The ARD is currently developing a monitoring protocol for less-expensive view monitoring using a digital camera. While this type of monitoring would not be adequate for regulatory purposes, it is useful for documenting visibility conditions and trends and provides an excellent means of sharing that information with the public.

All ERMN parks have an IMPROVE monitor within 120 km. The sites are as follows: Edwin B. Forsythe National Wildlife Refuge (NWR), New Jersey (Brigantine, BRIG1), operating since

1991; Connecticut Hill, New York (COHI1), operating since 2001; Addison Pinnacle, New York (ADPI1), operating since 2001; Quaker City, Ohio (QUCI1), operating since 2001; Arendtsville, Pennsylvania (AREN1), operating since 2001; Natural Bridge, Virginia (James River Face WA, JARI1), operating since 2000; Shenandoah National Park (NP), Virginia (SHEN1), operating since 1988; and Davis, West Virginia (Dolly Sods Wilderness Area (WA), DOSO1), operating since 1991.

IMPROVE provides maps of visibility conditions at all monitoring sites, pie charts of the pollutants that contribute to visibility impairment at each site, and trend data for sites that have been operating 10 years or longer (http://vista.cira.colostate.edu/views/Default.htm). One measurement used to report visibility is light extinction, or b_{ext}, reported in inverse megameters (Mm^{-1}). Light extinction occurs when particles in the air scatter or absorb light; extinction generally increases as particle concentrations in the air increase. Therefore, the higher the b_{ext}, the worse the visibility. The Regional Haze regulations require improvements in visibility on both the best (clearest), and the worst (haziest), days. In general, visibility is much better in the western, than in the eastern, U.S.

2002 IMPROVE data indicated b_{ext} at ERMN parks on the best visibility days ranged from 21 to 35 Mm^{-1}. On the worst visibility days, b_{ext} at Network parks ranged from 139 to 173 Mm^{-1}. These values are consistent with the 1995 to 1999 values provided in the NPS Air Atlas, i.e., 30 to 35 Mm^{-1} on the best visibility days and 168 to 191 Mm^{-1} on the worst visibility days. IMPROVE data showed that at all eight sites near ERMN parks, on an annual basis, impairment in 2002 was due primarily to ammonium sulfate (sources include coal combustion and oil refineries). The remainder was due to ammonium nitrate (sources include coal and natural gas combustion and automobiles), organics (sources include automobiles), elemental carbon (sources include wood burning) and coarse mass (larger than $PM_{2.5}$; sources unknown).

Trend data are available for Edwin B. Forsythe NWR, Shenandoah NP, and Davis. The data indicate an improvement in visibility at both Edwin B. Forsythe NWR and Shenandoah NP on the best and worst visibility days. While the Davis data show an improvement on days with worst visibility, there is no overall trend on days with best visibility.

Ozone

Ozone is created by a chemical reaction between oxides of nitrogen and volatile organic compounds in the presence of heat and sunlight. Some major sources of ozone-forming chemicals are motor vehicle exhaust and industrial emissions, gasoline vapors, and chemical solvents. High ozone concentrations cause respiratory problems in humans, and are a particular concern for those who are engaging in strenuous aerobic activity, such as hiking. Ozone also damages sensitive plant species. It injures plant leaves by causing a visible spotting or “stipple” on the upper surface of the leaves. Ozone can affect plant physiology by reducing growth, increasing susceptibility to disease, and increasing senescence.

None of the ERMN parks have continuous ozone monitors on-site, but passive ozone monitoring has been conducted during the summers of 1995 through 2003 at New River Gorge NR. All of the parks except Upper Delaware S&RR have continuous ozone monitors within 35 km. The Pennsylvania counties that contain Allegheny Portage Railroad NHS, Delaware Water Gap

NRA, Friendship Hill NHS, Johnstown Flood NMem, and Upper Delaware S&RR are designated nonattainment for the existing 1-hour ozone NAAQS. There are no 1-hour ozone nonattainment areas in West Virginia. EPA established a new NAAQS for ozone, which is based on an 8-hour ozone concentration, and they recently published their proposed list of nonattainment areas for the 8-hour standard (http://www.epa.gov/ttn/naaqs/ozone/index.html). While West Virginia has some proposed 8-hour ozone nonattainment areas, none are near ERMN parks. With the exception of Upper Delaware S&RR, all ERMN parks in Pennsylvania are in proposed 8-hour ozone nonattainment areas. Based on the 1995 to 1999 ozone values contained in the Air Atlas, all ERMN parks could be nonattainment for the 8-hour ozone NAAQS.

The NPS focuses on plant sensitivity to ozone for a couple of reasons. First, ozone is a regional pollutant and is, therefore, more likely to affect park resources than other gaseous pollutants such as sulfur dioxide and nitrogen oxide which quickly convert to other compounds. Second, the literature on ozone sensitivity is more recent and more reliable than that for other pollutants. The ARD contracted with an ozone effects expert from Cornell University to perform ozone injury risk assessments for all parks in the NPS I&M program. The risk assessments relied on the ozone concentration data provided in Air Atlas, vascular plant lists contained in NPSpecies, a list of ozone-sensitive vascular plant species developed at a 2003 expert workshop convened by the ARD (http://www2.nature.nps.gov/air/Pubs/index.htm), and the Palmer Z Index, which is used to indicate soil moisture status. Note that the ARD workshop report provides a general guide to ozone sensitivity. Differences in plant genetics, weather conditions, soil water availability, and ozone concentrations will affect whether or not a species exhibits injury in a park. In particular, studies have shown that plants will not take up ozone unless there is sufficient soil moisture. The risk assessments for the ERMN parks (Appendix 3) indicate the risk of ozone-induced foliar injury of sensitive vegetation is moderate at Allegheny Portage Railroad NHS, Bluestone NSR, Gauley River NRA, Johnstown Flood NMem, and New River Gorge NR, while the risk is high at Delaware Water Gap NRA, Fort Necessity NB, Friendship Hill NHS and Upper Delaware S&RR.

The U.S.D.A. Forest Service Forest Health Monitoring (FHM) program administers a nationwide biomonitoring program in partnership with the EPA and states. Ozone injury surveys are one component of the FHM program. According to a recent publication, FHM surveys in 2000 detected ozone injury on plots in the vicinity of all Pennsylvania parks in the ERMN; no injury was observed on plots located near West Virginia parks in the ERMN (Smith et al. 2003. *Environmental Monitoring and Assessment* 87:271-291). Because FHM does not provide plot location information, it is not known how close the plots are to NPS lands. A review of the NPS Research Permit and Reporting System shows that 16 FHM plots were established in and near Delaware Water Gap NRA in 2002. It is not known if ozone injury surveys were conducted on those plots.

Conclusions
All ERMN parks have both wet and dry deposition monitors within 80 km. Most likely, this coverage is adequate for Network parks. The ERMN parks in Pennsylvania all have MDN monitors within 60 km; none of the West Virginia parks have representative wet mercury deposition monitoring.

Assessing the sensitivity of ERMN park surface waters to atmospheric deposition is confounded by impacts from acid mine drainage in many of the parks and a shortage of recent data. Given the fish consumption advisories for mercury, PCBs and chlordane in Pennsylvania and West Virginia, the ERMN may want to consider long-term monitoring of contaminant levels in fish or other biota.

With the exception of Upper Delaware S&RR, particulate matter is monitored within 35 km of all ERMN parks. IMPROVE sites are located within 120 km of all Network parks. This coverage is likely adequate for assessing trends in regional visibility. If visibility impairment is a particular concern for any Network park, the ERMN may want to consider installing a digital camera to record and interpret visibility conditions.

With the exception of Upper Delaware S&RR, all ERMN parks have an ozone monitor within 35 km. The ERMN may want to consider installing a portable ozone monitor (Appendix 4) in parks where nearby monitors or the interpolated Air Atlas ozone estimates may not be representative of park conditions. It would be useful to document ozone concentrations at Upper Delaware S&RR, since the area is designated nonattainment for the 1-hour NAAQS but EPA is proposing to designate the area attainment for the 8-hour NAAQS.

The ozone injury risk assessments funded by the NPS ARD indicate a moderate to high risk of ozone injury of sensitive vegetation in all ERMN parks. The Network may want to consider conducting foliar injury surveys in ERMN parks.

Table 1. Summary of Deposition Data Collected in and near National Park Service Units in the Eastern Rivers and Mountains Network

PARK	NADP/NTN		CASTNet		MDN	
	LOCATION	**SITE #**	**LOCATION**	**SITE #**	**LOCATION**	**SITE #**
ALPO	On-site*	PA13	State College, PA 65 km NE	PSU106	On-site	PA13
	Pine Grove Mills, PA 60 km NE	PA42	Laurel Hill State Park, PA 80 km SW	LRL117		
	State College, PA 65 km NE	PA15				
BLUE	Horton Station, VA 45 km SE	VA13	Horton Station, VA 45 km SE	VPI120	None	
	Babcock State Park, WV 50 km N	WV04	Cedar Creek State Park, WV 135 km N	CDR119		
	Cedar Creek State Park, WV 135 km N	WV05				
DEWA	Milford, PA Within 10 km	PA72	Claryville, NY 70 km N	CAT175	Milford, PA Within 10 km	PA72
			Washington Crossing, NJ 80 km SE	WSP144		
FONE	Holbrook, PA* 60 km W	PA37	Laurel Hill State Park, PA 35 km NE	LRL117	Holbrook, PA 60 km W	PA37
FRHI	Holbrook, PA* 40 km NW	PA37	Laurel Hill State Park, PA 60 km NE	LRL117	Holbrook, PA 40 km NW	PA37

GARI	Babcock State Park, WV Within 10 km	WV04	Horton Station, VA 80 km S	VPI120	None	
	Horton Station, VA 80 km S	VA13	Cedar Creek State Park, WV 80 km N	CDR119		
	Cedar Creek State Park, WV 80 km N	WV05				
JOFL	ALPO* 10 km W	PA13	State College, PA 75 km NE	PSU106	ALPO 10 km W	PA13
	Pine Grove Mills, PA 70 km NE	PA42	Laurel Hill State Park, PA 70 km SW	LRL117		
	State College, PA 75 km NE	PA15				
NERI	Babcock State Park, WV Within 10 km	WV04	Horton Station, VA 50 km S	VPI120	None	
	Horton Station, VA 50 km S	VA13	Cedar Creek State Park, WV 90 km N	CDR119		
	Cedar Creek State Park, WV 90 km N	WV05				
UPDE	Milford, PA Within 10 km	PA72	Claryville, NY 45 km NE	CAT175	Milford, PA Within 10 km	PA72

NADP/NTN = National Atmospheric Deposition Program/National Trends Network
CASTNet = Clean Air Status and Trends Network
MDN = Mercury Deposition Network
ALPO = Allegheny Portage Railroad NHS
BLUE = Bluestone NSR
DEWA = Delaware Water Gap NRA

FONE = Fort Necessity NB
FRHI = Friendship Hill NHS
GARI = Gauley River NRA
JOFL = Johnstown Flood NMem
NERI = New River Gorge NR
UPDE = Upper Delaware S&RR
*ALPO and Holbrook are wet deposition sites in the Pennsylvania Atmospheric Deposition Monitoring Network, but are not in NADP

May 2004

Table 2. Summary of Ozone, IMPROVE and PM Data Collected in and near NPS Units in the Eastern Rivers and Mountains Network

PARK	OZONE		IMPROVE		PM	
	LOCATION	SITE #	LOCATION	SITE #	LOCATION	SITE #
ALPO	Altoona, PA 10 km NE	42-013-0801-44201	Arendtsville, PA 100 km SE	AREN1	Altoona, PA 10 km NE (PM_{10})	42-013-0801-81102
	Johnstown, PA 30 km SW	42-021-0011-44201	Davis, WV (Dolly Sods WA) 165 km SW	DOSO1		
BLUE	Sam Black Church, WV 35 km NE	54-025-0003-44201	Natural Bridge, VA (James River Face WA) 115 km E	JARI1	Keeney Knob, WV 20 km NE ($PM_{2.5}$)	54-089-0001-88101
			Davis, WV (Dolly Sods WA) 200 km NE	DOSO1	Beckley, WV 30 km NW ($PM_{2.5}$)	54-081-0002-88101
			Big Meadows, SHEN, VA 225 km NE	SHEN1		
			Quaker City, OH 260 km N	QUCI1		
DEWA	Easton, PA 30 km S	42-095-8000-44201	Arendtsville, PA 100 km SW	AREN1	Nazareth, PA 30 km SW (PM_{10})	42-095-1000-81102
			Connecticut Hill, NY 180 km NW	COHI1	Phillipsburg, NJ 30 km S ($PM_{2.5}$)	34-041-0006-88101
			Edwin B. Forsythe NWR, NJ 180 km SE	BRIG1		
			Addison Pinnacle, NY 220 km NW	ADPI1		
FONE	Morgantown, WV 35 km SW	54-061-0003-44201	Davis, WV (Dolly Sods WA) 75 km E	DOSO1	Morgantown, WV 35 km SW (PM_{10} and $PM_{2.5}$)	54-061-0003-88102 and 88101

			Quaker City, OH 125 km NE	QUCI1		

FRHI	Morgantown, WV 10 km S	54-061-0003-44201	Davis, WV (Dolly Sods WA) 75 km SE	DOSO1	Morgantown, WV 10 km S (PM_{10} and $PM_{2.5}$)	54-061-0003-88102 and 88101
			Quaker City, OH 100 km NE	QUCI1		
GARI	Sam Black Church, WV Within 10 km SE	54-025-0003-44201	Natural Bridge, VA (James River Face WA) 100 km SE	JARI1	Keeney Knob, WV 20 km S ($PM_{2.5}$)	54-089-0001-88101
			Davis, WV (Dolly Sods WA) 165 km NE	DOSO1		
			Quaker City, OH 200 km N	QUCI1		
			Big Meadows, SHEN, VA 205 km NE	SHEN1		
JOFL	Altoona, PA 20 km NE	42-013-0801-44201	Arendtsville, PA 110 km SE	AREN1	Altoona, PA 20 km NE (PM_{10})	42-013-0801-81102
	Johnstown, PA 25 km SW	42-021-0011-44201	Davis, WV (Dolly Sods WA) 165 km SW	DOSO1		
NERI	On-site*		Natural Bridge, VA (James River Face WA) 115 km E	JARI1	Keeney Knob, WV 20 km E ($PM_{2.5}$)	54-089-0001-88101
	Sam Black Church, WV 25 km NE	54-025-0003-44201	Davis, WV (Dolly Sods WA) 175 km NE	DOSO1	Beckley, WV 20 km SW ($PM_{2.5}$)	54-081-0002-88101
			Quaker City, OH 215 km N	QUCI1		
			Big Meadows, SHEN, VA	SHEN1		

			225 km NE			

UPDE	None		Connecticut Hill, NY 120 km NW	COHI1	None	
			Addison Pinnacle, NY 160 km W	ADPI1		
			Edwin B. Forsythe NWR, NJ 205 km S	BRIG1		
			Arendtsville, PA 270 km SW	AREN1		

IMPROVE = Interagency Monitoring of Protected Visual Environments Visibility Monitoring Program
PM_{10} = Particulate matter less than 10 microns in diameter
$PM_{2.5}$ = Particulate matter less than 2.5 microns in diameter
ALPO = Allegheny Portage Railroad NHS
BLUE = Bluestone NSR
DEWA = Delaware Water Gap NRA
FONE = Fort Necessity NB
FRHI = Friendship Hill NHS
GARI = Gauley River NRA
JOFL = Johnstown Flood NMem
NERI = New River Gorge NR
UPDE = Upper Delaware S&RR
SHEN = Shenandoah NP
WA = U.S.D.A. Forest Service Wilderness Area
NWR = U.S. Fish and Wildlife Service National Wildlife Refuge
*Ozone monitoring conducted with passive samplers at NERI from 1995 through 2003.

May 2004

Appendix 1. Air Atlas Pollution Estimates

	Ozone					NADP		Mm-1	Mm-1
Park	2nd_Hi_1hr	#1hr_>_100	4th_Hi_8hr	#8hr_>_85	Sum06_3_Mo	Total_S_kg/Ha	Total_N_kg/Ha	b_{ext}_Clear20%	b_{ext}_Hazy20%
ALPO	114	18	90	8	24	6.31	4.99	30	186
BLUE	110	10	85	6	28	4.58	3.54	35	190
DEWA	122	26	93	10	28	4.41	3.89	31	169
FONE	114	18	90	8	29	6.36	4.88	31	191
FRHI	114	18	89	8	34	6.32	4.81	31	191
GARI	112	13	86	6	25	4.94	3.81	34	190
JOFL	115	18	90	8	24	6.26	4.92	31	187
NERI	111	12	86	6	26	4.91	3.78	34	190
UPDE	122	23	91	8	22	4.56	4.07	30	168

May-04

Appendix 2. Description of Parameters Used in Air Atlas Summary Tables

The Air Atlas is a mini-GIS tool available on the Internet that provides national maps and an associated look-up table with baseline values of air quality parameters for all Inventory and Monitoring (I&M) parks in the U.S. The values are based on averaged 1995-1999 data. Air Atlas was produced by the National Park Service Air Resources Division (ARD) in association with the University of Denver. Air Atlas will serve as the Air Inventory for the parks and is available on the Internet at http://www2.nature.nps.gov/ard/gas/ (see section called *Air Atlas*).

The estimated air quality values provided in the look-up table are based on the center of the polygon defining the park or multiple units of the park. Because ozone is a regional pollutant, in most cases the look-up table values are likely representative of ozone concentrations throughout the park. Greater variability may exist for other parameters, such as deposition and visibility. In the future, the full Air Atlas dataset will be available on the internet, and users of ArcView and ArcGIS will be able to obtain air quality values for multiple points in a park by entering the latitude and longitude coordinates.

Air Atlas contains a comprehensive set of air quality parameters for all I&M parks. In addition, ARD has prepared a summary table that includes a select group of air quality parameters for each I&M network. The summary version is intended to provide parks with a synopsis useful for characterizing air quality conditions. Air quality parameters selected for the summary version are described below.

<u>Ozone Parameters</u>
Ozone can be expressed as concentration or cumulative dose. Relevant concentration and dose parameters include:

<u>2nd Hi 1-hr</u>: expressed in parts per billion (ppb), this value is the 2nd highest hourly value in a year and can be compared to the former Environmental Protection Agency (EPA) human health-based standard for ozone of 125 ppb (0.12 ppm).

<u>4th Hi 8-hr</u>: expressed in parts per billion (ppb), this value is the average hourly value in the 4th highest 8 hour period and can be compared to the present EPA human health-based standard for ozone of 85 ppb (0.08 ppm).

<u># 8 hrs > 85 ppb</u>: indicates how often the site would exceed the present ozone standard.

<u># 1 hr > 100 ppb</u>: indicates how often the site experiences high ozone concentrations; high concentrations contribute to vegetation (foliar) injury in sensitive plant species.

<u>SUM06_3Mo</u>: The running 90-day maximum sum of the 0800-2000 hourly concentrations of ozone equal to or greater than 0.06 ppm; represents cumulative exposure dose of ozone to plants.

Ozone is one of the most widespread air pollutants. Ozone is not emitted directly from smokestacks or vehicles, but is formed when other pollutants, primarily nitrogen oxides and volatile organic compounds, react in the atmosphere in the presence of sunlight, usually during the warm summer months. In addition to harming human health, ozone is phytotoxic, and causes considerable damage to vegetation throughout the world, including agricultural crops and native plants in natural ecosystems. The Environmental Protection Agency has established an ozone standard to protect human health; however, EPA has not set a standard to protect vegetation and there is much evidence to suggest that the human health-based standard is not protective of sensitive vegetation.

Ozone enters plants through leaf stomata and oxidizes plant tissue, causing changes in biochemical and physiological processes. Both visible foliar injury (e.g., stipple and chlorosis) and growth effects (e.g., premature leaf loss, reduced photosynthesis, and reduced leaf, root, and total dry weights) can occur in sensitive plant species. In a natural ecosystem, many other factors can ameliorate or magnify the extent of ozone injury at various times and places such as soil moisture, presence of other air pollutants, insects or diseases, and other environmental stresses.

Ozone injury can be induced by a sufficiently high seasonal dose of ozone (expressed as SUM06, in ppm-hrs), high peak concentrations of ozone (expressed in ppb), or a combination of both. Ozone effects to natural vegetation have been documented throughout the country, particularly in many areas of the East and in California. For sensitive natural vegetation in the East, researchers have recommended SUM06 effects endpoints of 8-12 ppm-hrs for foliar injury and 10-15 ppm-hrs for growth effects on tree seedlings in natural forest stands. In the West (Lassen Volcanic, Sequoia/Kings Canyon, and Yosemite NPs), researchers have found that foliar injury on ponderosa and Jeffrey pines ranges from about 15-50 percent at ozone values between 25-30 ppm-hrs. Sites with values above these endpoints may be at risk for vegetation injury if sensitive species are present. However, to adequately assess risk, other factors, including temperature and soil moisture, must be considered. In conditions of low moisture, for example, stomates may close, preventing ozone uptake. Ozone peak concentrations exceeding 100 ppb are also considered to be important in inducing injury and the number of hours in a year above 100 ppb may be significant for evaluating risk.

Atmospheric Deposition Parameters

Atmospheric deposition is the process by which airborne particles and gases are deposited to the earth's surface either through wet deposition (rain or snow), occult deposition (cloud or fog), or as a result of complex atmospheric processes such as settling, impaction, and adsorption, known as dry deposition. Although it is important to know total deposition, (i.e., the sum of wet, occult, and dry deposition) to park ecosystems, often only the wet deposition component is known, as it is the only one that is monitored routinely and extensively across the U.S. (at over 200 sites), as part of the National Atmospheric Deposition Program (NADP). Dry deposition is monitored at about 70 sites as part of the Clean Air Status and Trends Network (CASTNet). Clouds and fog may contribute significantly to total deposition at certain locations (e.g., high elevation areas and areas that experience a high frequency of clouds and fog), but monitoring cloud and fog deposition is difficult and is done at only a couple of locations in the U.S. Acids, nutrients, and toxics are the primary compounds within deposition that are of concern in park ecosystems.

Deposition can be expressed as concentration (e.g., micrograms per cubic meter or milligrams per liter) or deposition rates (e.g., kilograms per hectare per year – kg/ha/yr). Deposition rates are included in Air Atlas summaries, as these rates best characterize the amount of deposition an ecosystem experiences.

<u>NADP dep (kg/ha/yr)</u>: pollutant ions in wet deposition from rain or snow are measured by the National Atmospheric Deposition Program (NADP) and expressed as kg/ha/yr. NADP measures a comprehensive suite of anions and cations; deposition rates of total wet sulfur (S) and total wet inorganic nitrogen (N) (ammonium plus nitrate ions) are included in the summaries.

<u>NADP Total S (kg/ha/yr)</u>: total sulfur from sulfate ions in wet deposition.

<u>NADP Total N (kg/ha/yr)</u>: total inorganic nitrogen from ammonium and nitrate ions in wet deposition.

Atmospheric deposition affects ecosystems in a variety of ways, including acidification, fertilization or eutrophication, and accumulation of toxics. Acid deposition from sulfur and nitrogen compounds affects freshwater lakes, streams, and watersheds. Acid deposition effects include changes in water chemistry that affect algae, fish, submerged vegetation, and amphibian and aquatic invertebrate communities. Deposition can also cause changes in soil that affect soil microorganisms, understory plants, and trees. Excess nitrogen deposition can cause unwanted fertilization effects, leading to changes in plant community structure and diversity. In estuaries and coastal waters, nitrogen can cause algae blooms, decreases in dissolved oxygen, and loss of seagrasses (i.e., eutrophication).

All areas of the country are experiencing levels of atmospheric deposition above natural levels. The ability of ecosystems to deal with increased levels of deposition varies widely. High elevation ecosystems in the Rocky Mountains, Cascades, Sierra Nevada, southern California, and eastern U.S. are generally the most sensitive to atmospheric deposition due to their poor ability to neutralize acid deposition. Other sensitive areas include the upper Midwest, New England, and Florida, including the shallow bays and estuaries along the Atlantic and Gulf Coasts. Streams in both Shenandoah and Great Smoky Mountains NPs are experiencing chronic and episodic acidification and brook trout fisheries in Shenandoah have been affected. Rocky Mountain NP is also currently undergoing subtle changes in aquatic and terrestrial ecosystems attributable to atmospheric deposition. In some areas, excess nitrogen deposition has caused shifts in plant species composition, with native species being replaced by invasive and exotic species that are better able to utilize nitrogen.

Visibility Parameters
A number of visibility indices, or measurements, can be used to express visibility conditions. The measurement used in Air Atlas summaries is light extinction.

<u>bextClear</u>: annual average light extinction, expressed in inverse megameters, on the 20 percent clearest days

<u>bextHazy</u>: annual average light extinction, expressed in inverse megameters, on the 20 percent haziest days

Light extinction, expressed in the form of inverse megameters (Mm^{-1}), is proportional to the amount of light lost because of scattering or absorption by particles in the air as the light travels over a million meters (one million meters = one megameter). Light extinction occurs when particles in the air scatter or absorb light; extinction generally increases as particle concentrations in the air increase.

Extinction can be measured directly, with a transmissometer and nephelometer, or it can be calculated from representative aerosol measurements. Air Atlas extinction estimates, so-called "reconstructed" estimates, are calculated from aerosol measurements. Total extinction is the sum of the individual extinctions caused by gases, particles, and air molecules in the atmosphere. Relative humidity, as well as particle concentrations, is considered in the equation, as relative humidity increases the extinction efficiency of certain particles.

Light extinction is averaged for the 20 percent clearest and the 20 percent haziest days in an area. The Environmental Protection Agency's 1999 Regional Haze Regulations require that reasonable progress be made to restore visibility to natural background conditions within 60 years. States are to establish goals for each Class I area to improve visibility on the haziest days (defined as the 20 percent haziest day) and ensure no degradation occurs on the clearest days (defined as the 20 percent clearest days). Emissions reductions that benefit visibility in Class I areas are also expected to benefit visibility in all other areas.

Visual range (VR) is another index used to describe visibility. Because VR is not particularly useful for assessing the quality of scenic vistas (clarity, color), light extinction is used in Air Atlas. However, VR is sometimes useful for describing visibility to the general public. VR is expressed as length; extinction is expressed as 1/length. The relationship between VR and extinction is:

$$\mathrm{VR} = \frac{3.912}{\mathrm{bext}(\mathrm{km}^{-1})} = \frac{3912}{\mathrm{bext}(\mathrm{Mm}^{-1})}$$

Appendix 3. OZONE INJURY RISK ASSESSMENT

EASTERN RIVERS AND MOUNTAINS NETWORK

(May 2004)

ALLEGHENY PORTAGE RAILROAD NATIONAL HISTORIC SITE (ALPO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster acuminatus	Whorled aster	Asteraceae
Fraxinus americana	White ash	Oleaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus banksiana	Jack pine	Pinaceae
Pinus rigida	Pitch pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by Krieging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for ALPO

	1995	1996	1997	1998	1999
Sum06	20	18	23	26	31
W126	30.9	23.9	32.2	44.0	38.2
N60	505	422	514	744	655
N80	117	55	111	183	133
N100	16	4	21	33	14

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by Krieging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at ALPO					
	1995	1996	1997	1998	1999
Month 1	2.57	0.66	-0.37	-0.89	-2.67
Month 2	-1.29	4.22	-1.75	-1.19	-1.70
Month 3	-3.25	-0.22	1.54	-2.03	-3.36

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at ALPO					
	1995	1996	1997	1998	1999
April	-1.10	-0.91	-2.49	2.93	2.21
May	0.38	1.41	1.81	-0.20	-2.67
June	2.57	0.66	-0.37	1.02	-1.70
July	-1.29	4.22	-1.75	-0.89	-3.36
August	-3.25	-0.22	1.54	-1.19	0.72
September	-1.88	8.51	1.49	-2.03	0.68
October	2.69	2.10	-1.30	-1.36	-0.79

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours every year. These levels of exposure can injure vegetation.

- Soil moisture levels during the 90-day Sum06 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The years with the highest ozone exposure values, 1999 and 1998, show three and two months of mild to severe drought, respectively. The year with the lowest exposure, 1996, experienced favorable conditions. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure. The four highest ozone years each experienced three or four months of mild to severe drought. In the lowest exposure year, 1996, soil moisture conditions were favorable.

The risk of foliar ozone injury to plants at Allegheny Portage Railroad National Historic Site is moderate. The Sum06 threshold for injury is consistently satisfied, and the W126 index criteria are generally fulfilled. The N80 and N100 counts are high, but significantly lower in one year. The inverse relationship between ozone exposure and soil moisture is a significant factor affecting the potential for injury at the site. The years in which exposures exceed the injury thresholds are also ones in which there are three to four months of mild to severe drought. These moisture conditions constrain the uptake of ozone and reduce the likelihood that the exposures will produce foliar injury. When drought is moderate and severe in high ozone years, the uptake of ozone is significantly diminished, and, in spite of the high levels of exposure, the risk of injury is greatly reduced. One year, 1996, has favorable soil moisture conditions, but ozone exposures are lower. This year, however, suggests that levels of exposure capable of producing foliar injury may also occur at the site under conditions of minor drought or normal soil moisture. The probability of foliar injury developing may greatest during years in which ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, common milkweed, yellow-poplar, American sycamore, quaking aspen, black cherry, Allegheny blackberry, cut-leaf coneflower, and American elder.

BLUESTONE NATIONAL SCENIC RIVER
(BLUE)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Aesculus octandra	Yellow buckeye	Hippocastanacea
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias exaltata	Tall milkweed	Asclepiadaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster macrophyllus	Big-leaf aster	Asteraceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus rigida	Pitch pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Verbesina occidentalis	Crownbeard	Asteraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100

Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by Krieging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for BLUE					
	1995	1996	1997	1998	1999
Sum06	20	21	26	35	31
W126	36.5	31.8	41.1	53.1	49.5
N60	702	587	757	968	937
N80	73	61	98	182	149
N100	6	4	5	20	16

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by Krieging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at BLUE					
	1995	1996	1997	1998	1999
Month 1	-2.22	-0.66	0.82	2.42	-1.03
Month 2	-2.76	4.73	0.50	-1.48	-2.58
Month 3	0.76	0.41	0.30	-1.56	-2.18

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at BLUE					
	1995	1996	1997	1998	1999
April	-1.98	-0.66	-0.84	2.50	0.47
May	2.67	4.73	0.82	3.09	-1.03
June	3.62	0.41	0.50	2.42	-2.58
July	-2.22	-0.59	0.30	-1.48	-2.18
August	-2.76	2.36	-0.72	-1.56	-1.45
September	0.76	3.75	-0.74	-2.96	1.05
October	0.65	-0.17	-1.99	-2.14	-0.07

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in three of the years, although concentrations exceeded 100 ppb every year. The criteria for injury under the W126 exposure index are generally satisfied.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours every year. These levels of exposure can injure vegetation.

- Soil moisture levels associated with the 90-day Sum06 accumulation period levels of ozone appear to be inversely related to ozone concentrations, when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury.

> The years with the highest ozone exposure values, 1998 and 1999, had, respectively, two and three months of mild and moderate drought. However, there were two months of moderate drought in 1995, the year with the lowest ozone exposure. The two intermediate ozone years had favorable soil moisture throughout. Soil moisture levels associated with the seasonal W126 index also appear to be inversely related to ozone concentrations with a pattern that is not consistent. The two highest ozone years, 1998 and 1999, each had four months of mild and moderate drought, respectively. While the year with the lowest ozone exposure, 1996, had favorable conditions, the second lowest year had three months of mild and moderate drought.

The risk of foliar ozone injury to plants at Bluestone National Scenic River is moderate. The Sum06 threshold for injury is consistently satisfied, and the W126 index criteria are generally fulfilled. The N80 and N100 counts are high, but significantly lower in two years. The inverse relationship between ozone exposure and soil moisture is a significant factor affecting the potential for injury at the site. The years in which exposures exceed the injury thresholds are also ones in which there are three to four months of mild to severe drought. These moisture conditions constrain the uptake of ozone and reduce the likelihood that the exposures will produce foliar injury. When drought is moderate and severe in high ozone years, the uptake of ozone is significantly diminished, and, in spite of the high levels of exposure, the risk of injury is greatly reduced. The two years that have favorable soil moisture conditions, 1996 and 1997, also have ozone exposures that are lower. These years, however, suggest that levels of exposure capable of producing foliar injury may also occur at the site under conditions of minor drought or normal soil moisture. The probability of foliar injury developing may be greatest during years when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, tall milkweed, common milkweed, big-leaf aster, white ash, yellow-poplar, American sycamore, Allegheny blackberry, cut-leaf coneflower, American elder, crownbeard, and northern fox grape.

DELAWARE WATER GAP NATIONAL RECREATION AREA (DEWA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias exaltata	Tall milkweed	Asclepiadaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster acuminatus	Whorled aster	Asteraceae
Aster macrophyllus	Big-leaf aster	Asteraceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Philadelphus coronarius	Sweet mock-orange	Hydrangeaceae
Pinus rigida	Pitch pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by Krieging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for DEWA					
	1995	1996	1997	1998	1999
Sum06	21	16	20	23	28
W126	32.8	25.3	29.1	36.4	39.9
N60	511	397	452	608	630
N80	160	96	128	160	184
N100	29	13	21	14	41

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by Krieging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at DEWA					
	1995	1996	1997	1998	1999
Month 1	-1.94	0.86	-1.37	-1.19	-2.14
Month 2	-0.56	2.84	-1.72	-2.13	-3.15
Month 3	-3.49	-1.70	1.36	-0.66	-1.97

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at DEWA					
	1995	1996	1997	1998	1999
April	-1.53	1.90	-1.44	1.60	-1.41
May	-1.22	-0.18	-0.32	0.78	-1.13
June	-1.94	0.86	-1.37	3.26	-2.14
July	-0.56	2.84	-1.72	-1.19	-3.15
August	-3.49	-1.70	1.36	-2.13	-1.97
September	-0.99	1.26	0.11	-0.66	6.14
October	3.91	2.89	-1.41	-0.17	-0.10

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours every year. These levels of exposure can injure vegetation.

- Soil moisture levels during the 90-day Sum06 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The year with the highest ozone exposure value, 1999, had three months of mild to moderate drought, while the lowest ozone year, 1996, had one month of mild drought. The three intermediate years each had two months of mild to severe drought. Soil moisture levels associated with the seasonal W126 index also appear to be inversely related to ozone concentrations, but the pattern is not consistent. The highest ozone year, 1999, had five months of mild to severe drought and the lowest year, 1996, had one month of mild drought. However, the second highest ozone year, 1998, had two months of drought, while the second lowest year, 1997, had four months of mild drought. Irregularities in the inverse association exist, however the overall Sum06 and W126 assessments support the relationship.

The risk of foliar ozone injury to plants at Delaware Water Gap National Recreation Area is high. The Sum06 and W126 threshold criteria are both satisfied, and the N80 and N100 counts are high. While the levels of ozone exposure consistently create the potential for injury, the inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1996 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, tall milkweed, common milkweed, big-leaf aster, redbud, white ash, yellow-poplar, American sycamore, quaking aspen, black cherry, Allegheny blackberry, cut-leaf coneflower, American elder, common snowberry, and northern fox grape.

FORT NECESSITY NATIONAL BATTLEFIELD
(FONE)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Asclepias syriaca	Common milkweed	Asclepiadaceae
Fraxinus americana	White ash	Oleaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus rigida	Pitch pine	Pinaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by Krieging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for FONE					
	1995	1996	1997	1998	1999
Sum06	21	18	22	29	32
W126	32.5	27.2	30.8	43.5	40.7
N60	544	488	494	741	711
N80	130	74	112	191	148
N100	21	7	17	36	19

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by Krieging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at FONE					
	1995	1996	1997	1998	1999
Month 1	-0.52	1.23	-0.80	-1.48	-1.07
Month 2	-1.84	1.41	-2.79	-0.83	-3.31
Month 3	-3.07	-0.63	1.58	-2.13	-1.30

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at FONE					
	1995	1996	1997	1998	1999
April	-1.16	0.57	-2.08	1.97	1.42
May	0.64	1.19	2.81	-2.20	-1.07
June	-0.52	1.23	-0.80	1.33	-3.31
July	-1.84	1.41	-2.79	-1.48	-1.30
August	-3.07	-0.63	1.58	-0.83	-1.86
September	-2.15	4.21	0.69	-2.13	-0.86
October	0.25	1.76	-1.71	-1.24	-1.58

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours every year. These levels of exposure can injure vegetation.

- Soil moisture levels during the 90-day Sum06 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The year with the highest and second highest ozone exposure values, 1999 and 1998, experienced three and two months of mild to severe drought, respectively. The year with the lowest ozone exposure, 1996, had favorable soil moisture conditions. The two intermediate ozone years had similar levels of exposure and one and two months of drought each. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure. In the highest ozone years, 1998 and 1999, there were four and five months, respectively, of mild to severe drought. The two mid-ozone years, 1995 and 1997, had four and three months of mild to severe drought, while the lowest ozone year, 1996, had favorable soil moisture conditions throughout.

The risk of foliar ozone injury to plants at Fort Necessity National Battlefield is high. The Sum06 and W126 threshold criteria are both satisfied, and the N80 and N100 counts are generally high. While the levels of ozone exposure consistently create the potential for injury, the inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1996 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: common milkweed, white ash, yellow-poplar, black cherry, Allegheny blackberry, and American elder.

FRIENDSHIP HILL NATIONAL HISTORIC SITE
(FRHI)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Aesculus octandra	Yellow buckeye	Hippocastanaceae
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus rigida	Pitch pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by Krieging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for FRHI					
	1995	1996	1997	1998	1999
Sum06	20	18	24	32	34
W126	32.2	28.2	30.8	45.2	45.9
N60	540	505	501	772	815
N80	128	78	107	201	163
N100	20	8	15	36	19

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by Krieging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at FRHI					
	1995	1996	1997	1998	1999
Month 1	-0.52	1.23	-0.80	-1.48	-1.07
Month 2	-1.84	1.41	-2.79	-0.83	-3.31
Month 3	-3.07	-0.63	1.58	-2.13	-1.30

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at FRHI					
	1995	1996	1997	1998	1999
April	-1.16	0.57	-2.08	1.97	1.42
May	0.64	1.19	2.81	-2.20	-1.07
June	-0.52	1.23	-0.80	1.33	-3.31
July	-1.84	1.41	-2.79	-1.48	-1.30
August	-3.07	-0.63	1.58	-0.83	-1.86
September	-2.15	4.21	0.69	-2.13	-0.86
October	0.25	1.76	-1.71	-1.24	-1.58

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours every year. These levels of exposure can injure vegetation.

- Soil moisture levels during the 90-day Sum06 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The years with the highest and second highest ozone exposure values, 1999 and 1998, experienced three and two months of mild to severe drought, respectively. The year with the lowest ozone exposure, 1996, had favorable soil moisture conditions. The two intermediate ozone years had one and two months of drought each. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure. In the highest ozone years, 1999 and 1998, there were five and four months, respectively, of mild to severe drought. The two mid-ozone years, 1995 and 1997, had four and three months of mild to severe drought. In the lowest ozone year, 1996, soil moisture conditions were favorable throughout.

The risk of foliar ozone injury to plants at Friendship Hill National Historic Site is high. The Sum06 and W126 threshold criteria are both satisfied, and the N80 and N100 counts are generally high. While the levels of ozone exposure consistently create the potential for injury, the inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1996 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, common milkweed, redbud, white ash, yellow-poplar, American sycamore, black cherry, Allegheny blackberry, cut-leaf coneflower, and American elder.

GAULEY RIVER NATIONAL RECREATION AREA
(GARI)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Aesculus octandra	Yellow buckeye	Hippocastanaceae
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias exaltata	Tall milkweed	Asclepiadaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster macrophyllus	Big-leaf aster	Asteraceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus rigida	Pitch pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Verbesina occidentalis	Crownbeard	Asteraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by Krieging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for GARI

	1995	1996	1997	1998	1999
Sum06	19	15	15	23	29
W126	40.3	27.0	36.2	52.3	48.4
N60	757	485	673	955	889
N80	100	53	72	195	150
N100	11	4	4	26	18

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by Krieging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at GARI					
	1995	1996	1997	1998	1999
Month 1	0.96	-1.05	-1.13	-1.91	-3.46
Month 2	-3.09	4.40	0.91	-1.51	-3.38
Month 3	-1.88	1.51	0.44	-2.06	-1.56

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at GARI					
	1995	1996	1997	1998	1999
April	-1.89	-0.78	-1.11	1.15	-1.35
May	2.18	6.67	1.50	0.09	-1.66
June	0.96	-1.05	-0.50	5.38	-3.46
July	-3.09	4.40	-1.13	-1.91	-3.38
August	-1.88	1.51	0.91	-1.51	-1.56
September	-1.84	5.53	0.44	-2.06	-1.10
October	-0.55	0.45	-1.49	-2.48	-0.28

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value exceeds the threshold each year and the N100 count generally meets the threshold requirement.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb. The N-value for 100 ppb was highly variable, but reached a significant number of hours in three of the years. The higher levels of exposure can injure vegetation.

- Soil moisture levels during the 90-day Sum06 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The years with the highest and second highest ozone exposure values, 1999 and 1998, each experienced three months of mild to severe drought. The two years with the same and lowest ozone exposure, 1996 and 1997, each had one month of mild drought. The intermediate ozone year had two months of drought. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure. In the highest ozone years, 1998 and 1999, there were four and six months, respectively, of mild to severe drought. The two mid-ozone years, 1995 and 1997, had four and three months of mild to severe drought. In the lowest ozone year, 1996, there was one month of mild drought.

The risk of foliar ozone injury to plants at Gauley River National Recreation Area is moderate. The Sum06 threshold for injury is consistently satisfied, and the W126 index criteria are generally fulfilled. The N80 and N100 counts are high, but significantly lower in two years. The inverse relationship between ozone exposure and soil moisture is a significant factor affecting the potential for injury at the site. The years in which exposures exceed the injury thresholds are also ones in which there are four to six months of mild to severe drought. These moisture conditions constrain the uptake of ozone and reduce the likelihood that the exposures will produce foliar injury. When drought is moderate and severe in high ozone years, the uptake of ozone is significantly diminished, and, in spite of the high levels of exposure, the risk of injury is greatly reduced. Two years, 1996 and 1997, have favorable to generally favorable soil moisture conditions, but ozone exposures are lower. These years, however, suggest that levels of exposure capable of producing foliar injury may also occur at the site under conditions of minor drought or normal soil moisture. The probability of foliar injury developing may greatest during years in which ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, tall milkweed, common milkweed, big-leaf aster, redbud, white ash, yellow-poplar, American sycamore, black cherry, Allegheny blackberry, cut-leaf coneflower, American elder, and crownbeard.

JOHNSTOWN FLOOD NATIONAL MEMORIAL
(JOFL)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster acuminatus	Whorled aster	Asteraceae
Fraxinus americana	White ash	Oleaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by Krieging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for JOFL

	1995	1996	1997	1998	1999
Sum06	20	18	20	25	30
W126	30.6	23.4	30.4	40.7	36.2
N60	497	413	482	684	618
N80	123	58	107	173	133
N100	19	5	20	33	17

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by Krieging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at JOFL					
	1995	1996	1997	1998	1999
Month 1	2.57	0.66	-0.37	-0.89	-2.67
Month 2	-1.29	4.22	-1.75	-1.19	-1.70
Month 3	-3.25	-0.22	1.54	-2.03	-3.36

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at JOFL					
	1995	1996	1997	1998	1999
April	-1.10	-0.91	-2.49	2.93	2.21
May	0.38	1.41	1.81	-0.20	-2.67
June	2.57	0.66	-0.37	1.02	-1.70
July	-1.29	4.22	-1.75	-0.89	-3.36
August	-3.25	-0.22	1.54	-1.19	0.72
September	-1.88	8.51	1.49	-2.03	0.68
October	2.69	2.10	-1.30	-1.36	-0.79

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value exceeds the threshold each year and the N100 count generally meets the threshold requirement.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours in most years. The levels of high exposure can injure vegetation.

- Soil moisture levels during the 90-day Sum06 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The years with the highest and second highest ozone exposure values, 1999 and 1998, experienced three and two months of mild to severe drought, respectively. The year with the lowest ozone exposure, 1996, had favorable soil moisture conditions. The two intermediate ozone years had one and two months of drought each. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure, although there were some inconsistencies. The highest ozone years, 1998 and 1999, each had three months of mild to severe drought. The lowest ozone year, 1996, had favorable soil moisture conditions throughout. The two mid-ozone years, 1995 and 1997, had four and three months of mild to severe drought, and were somewhat out of the inverse pattern.

The risk of foliar ozone injury to plants at Johnstown Flood National Memorial is moderate. The Sum06 threshold for injury is consistently satisfied, and the W126 index criteria are generally fulfilled. The N80 and N100 counts are high, but significantly lower in one year. The inverse relationship between ozone exposure and soil moisture is a significant factor affecting the potential for injury at the site. The years in which exposures exceed the injury thresholds are also ones in which there are three to four months of mild to severe drought. These moisture conditions constrain the uptake of ozone and reduce the likelihood that the exposures will produce foliar injury. When drought is moderate and severe in high ozone years, the uptake of ozone is significantly diminished, and, in spite of the high levels of exposure, the risk of injury is greatly reduced. One year, 1996, has favorable soil moisture conditions, but ozone exposures are lower. This year, however, suggests that levels of exposure capable of producing foliar injury may also occur at the site under conditions of minor drought or normal soil moisture. The probability of foliar injury developing may greatest during years in which ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: common milkweed, white ash, yellow-poplar, quaking aspen, black cherry, Allegheny blackberry, cut-leaf coneflower, and American elder.

NEW RIVER GORGE NATIONAL RIVER
(NERI)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias exaltata	Tall milkweed	Asclepiadaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster acuminatus	Whorled aster	Asteraceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus rigida	Pitch pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Populus tremuloides	Quaking aspen	Salicaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Verbesina occidentalis	Crownbeard	Asteraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by Krieging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for NERI					
	1995	1996	1997	1998	1999
Sum06	19	14	16	25	29
W126	44.3	28.7	40.8	59.7	53.3
N60	848	520	771	1109	1001
N80	100	48	79	209	157
N100	9	3	4	24	15

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by Krieging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at NERI					
	1995	1996	1997	1998	1999
Month 1	0.96	-1.05	-1.13	-1.91	-3.46
Month 2	-3.09	4.40	0.91	-1.51	-3.38
Month 3	-1.88	1.51	0.44	-2.06	-1.56

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at NERI					
	1995	1996	1997	1998	1999
April	-1.89	-0.78	-1.11	1.15	-1.35
May	2.18	6.67	1.50	0.09	-1.66
June	0.96	-1.05	-0.50	5.38	-3.46
July	-3.09	4.40	-1.13	-1.91	-3.38
August	-1.88	1.51	0.91	-1.51	-1.56
September	-1.84	5.53	0.44	-2.06	-1.10
October	-0.55	0.45	-1.49	-2.48	-0.28

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value exceeds the threshold each year and the N100 count generally meets the threshold requirement.
- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours most years. The high levels of exposure can injure vegetation.
- Soil moisture levels during the 90-day Sum06 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This

relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The years with the highest and second highest ozone exposure values, 1999 and 1998, each experienced three months of mild to severe drought. The years with the lowest and second lowest ozone exposure, 1996 and 1997, each experienced one month of mild drought. The intermediate ozone year, 1995, had two months of drought. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure. In the highest ozone years, 1998 and 1999, there were four and six months, respectively, of mild to severe drought. The two mid-ozone years, 1995 and 1997, had four and three months of drought, and the lowest ozone year, 1996, had one month of mild drought.

The risk of foliar ozone injury to plants at New River Gorge National River is moderate. The Sum06 threshold for injury is consistently satisfied, and the W126 index criteria are generally fulfilled. The N80 and N100 counts are high, but significantly lower in two years. The inverse relationship between ozone exposure and soil moisture is a significant factor affecting the potential for injury at the site. The years in which exposures exceed the injury thresholds are also ones in which there are three to four months of mild to severe drought. These moisture conditions constrain the uptake of ozone and reduce the likelihood that the exposures will produce foliar injury. When drought is moderate and severe in high ozone years, the uptake of ozone is significantly diminished, and, in spite of the high levels of exposure, the risk of injury is greatly reduced. Two years, 1996 and 1997, have favorable or generally favorable soil moisture conditions, but ozone exposures are lower. These years, however, suggest that levels of exposure capable of producing foliar injury may also occur at the site under conditions of minor drought or normal soil moisture. The probability of foliar injury developing may greatest during years in which ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, tall milkweed, common milkweed, redbud, white ash, yellow-poplar, American sycamore, quaking aspen, Allegheny blackberry, cut-leaf coneflower, American elder, common snowberry, crownbeard, and northern fox grape.

UPPER DELAWARE SCENIC AND RECREATIONAL RIVER (UPDE)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster acuminatus	Whorled aster	Asteraceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus rigida	Pitch pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sassafras albidum	Sassafras	Lauraceae
Spartina alterniflora	Smooth cordgrass	Poaceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

<u>Sum06</u> -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

<u>W126</u> -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by Krieging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for UPDE					
	1995	1996	1997	1998	1999
Sum06	19	14	18	20	23
W126	29.4	23.3	26.3	31.3	34.6
N60	461	365	411	524	544
N80	132	83	104	124	146
N100	24	13	14	11	30

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by Krieging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at UPDE					
	1995	1996	1997	1998	1999
Month 1	-1.94	0.86	-1.37	-1.19	-1.13
Month 2	-0.56	2.84	-1.72	-2.13	-2.14
Month 3	-3.49	-1.70	1.36	-0.66	-3.15

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at UPDE					
	1995	1996	1997	1998	1999
April	-1.53	1.90	-1.44	1.60	-1.41
May	-1.22	-0.18	-0.32	0.78	-1.13
June	-1.94	0.86	-1.37	3.26	-2.14
July	-0.56	2.84	-1.72	-1.19	-3.15
August	-3.49	-1.70	1.36	-2.13	-1.97
September	-0.99	1.26	0.11	-0.66	4.14
October	3.91	2.89	-1.41	-0.17	-0.10

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours every year. These levels of exposure can injure vegetation.

- Soil moisture levels during the 90-day Sum06 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The year with the highest ozone exposure value, 1999, experienced three months of mild to severe drought. The three intermediate ozone years had similar levels of exposure and each had two months of drought. The year with the lowest ozone exposure, 1996, had one month of mild drought. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure. In the highest ozone year, 1999, there were five months of mild to severe drought. The three mid-ozone years, 1998, 1995 and 1997, had two, four and three months of drought, respectively, and the lowest ozone year, 1996, had one month of mild drought.

The risk of foliar ozone injury to plants at Upper Delaware Scenic and Recreational River is high. The Sum06 and W126 threshold criteria are both satisfied, and the N80 and N100 counts are high. While the levels of ozone exposure consistently create the potential for injury, the inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1996 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: common milkweed, white ash, yellow-poplar, American sycamore, quaking aspen, black cherry, Allegheny blackberry, cut-leaf coneflower, and northern fox grape.

Appendix 4. Portable Ozone Monitoring Systems

Introduction

The Air Resources Division has developed a small, low-power, self-contained system for monitoring ozone and weather parameters in remote locations. These systems do not require the infrastructure of a normal monitoring station such as utilities, a shelter, a sampling tower, or road access. The standard configuration has an ozone analyzer, weather sensors, a datalogger, solar-power system, and a communications package. Ozone data is collected as hourly averages and transmitted back to a central office for validation checks and storage in a database. Currently, the ozone analyzer is not EPA certified as a reference method for regulatory purposes, however, we have done extensive intercomparisons and temperature tests on the analyzers and find them to be quite reliable. The "portable" aspect is that they can easily be shipped to a site and assembled in a few hours. Relocation over short distances can be done by disconnecting a few parts, picking up the unit (two person operation), and transporting in a pickup truck. Thus, moving a systems is much less effort and expense that with a standard monitoring station.

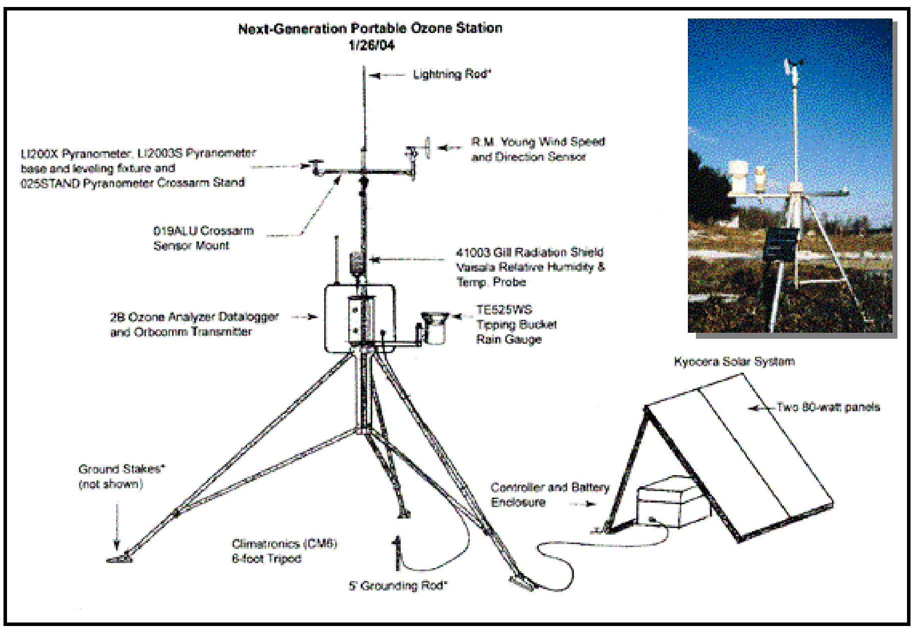

Figure 1.   Diagram of the portable ozone monitoring system and components. Inset picture is approximately what the unit will look like in the field.

Uses for the portable ozone system

The portable system is recommended for warm season use as a temporary station (1 – 5 years) in remote areas where power, phone, access, and shelter are not easily provided. The monitoring objectives may include survey monitoring to establish a baseline, monitoring in associate with vegetation injury studies, spatial distribution studies, or for monitoring of areas where changes in ozone from development, fires, or other pollutant source activities are expected.

ARD portable ozone systems facility

Initial development and testing was done by ARD of the portable systems. Nine systems have been built by ARD for use in parks. Since deployments are meant to be temporary, these units will be available for use in other parks than their initial locations. We also have the facilities to build more portable ozone systems, though not necessarily the budget to do so. The central office, field support, and database functions are available through our field support contractor to handle the currently deployed systems and additional systems.

What this means for potential users is that the current batch of portable ozone systems will be redeployed according to a ranked priority scheme as units become available. Park units, networks, or regions with funds to help build additional units can “lease” units for shorter deployments or buy units if they intend to use them long-term. ARD will provide the option of support services through our field support contractor.

Costs to operate the portable ozone systems

At present the initial fabrication, testing, and deployment of a unit costs approximately $20k. Annual operational expenses are expected to be about $8k. ARD presently provides a small amount of support to help cover an operator and other costs to a park. We do not anticipate being able to expand this kind of support, however, so parks may have to provide an operator without additional compensation. Fortunately, operator duties are only about 1-2 hours per week over the course of a season. “Leasing” options can be discussed.

Options available for system configurations

Flexibility is part of the design for the portable ozone monitoring systems. The table below shows the options that are readily available and have been tested with out monitoring equipment.

Base system	**Pollutant measurements**	**Weather sensors**	**Communications**	**Power**
Tripod tower*	Ozone analyzer*	Winds*	Cell phone*	Solar cells, battery pack – DC*
Campbell datalogger*	CASTNet-style filter-pack (SO_2, NO_3, SO_4, HNO_3)	Relative humidity*	Satellite modem	AC line power
Instrument box*		Solar radiation*	Storage module	
Automated zero check system*		Ambient temperature*	Near real-time web data presentation	
Inlet with Teflon filter*		Rainfall*	Hard-line phone	
		Other sensors	Radio phone extended	

* Standard configuration components

Further Information

As more information, test results, examples of deployments, and data become available, they will be posted on the web site at http://www2.nature.nps.gov/air/studies/portO3.htm .

A monitoring protocol document describing the portable ozone system and other ozone monitoring options is being prepared.

Contacts

The NPS Air Resources Division is available for consultation and has the facility and contractors to help put these units into field locations. Call or email:

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